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Development of a Low Cost Wireless Sensor Network for a Real Time Paddy Field Monitoring System

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Abstract

The impressive benefits of wireless sensor networks (WSNs) have led many researchers to study and explorer the wireless sensor network for the agricultural area. Most of these studies focus on ways of how to develop the sensor networks for agriculture without describing or discussing the cost aspect of the WSN and the easing of the system development. The aim of this paper is to develop a low cost wireless sensor network for a real time paddy field monitoring system based on an open source Arduino platform. The platform then is combined with the ZigBee-based communication module, and low cost sensor devices for agricultural applications such as temperature, air humidity, and soil humidity. The proposed WSN in this paper greatly reduces the cost of the development and provides an easy way for its implementation. Evaluation results show that the proposed WSN is able to sense the paddy field conditions and send the sensing results to the Internet cloud server for real-time displayed information.

Keywords: *WSN, Paddy Field, Arduino, IoT, Precision Agriculture, Gowa*

1. Introduction

In precision agriculture (PA) today, wireless sensor network (WSN) technologies have been widely used as a supporting tool to collect a field data in a specific location and real time manner. The wireless sensor network system is composed of several devices − namely sensor nodes or motes [1]. The sensor nodes with attached devices such as a microcontroller, sensors, memory, a power source, and communication devices are distributed in the area of interest to gather the condition of the field or crops, transmit the sensed data to a base station for analysis, and then present information to the agricultural stakeholders (*i.e.*, farmers, agriculture companies, government). Figure 1, shows an example of the sensor nodes of the WaterSense project in agriculture [2].

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Figure 1. WaterSense Project in Agricultural

Several projects have been done so far to study the sensor network for the agricultural area such as monitoring systems and recording of field data [3-4], precision horticulture [5], sensor network for wine field [6], and sensor network applications for green house control [7]. However, these studies focus on ways of how to develop the sensor networks for agriculture without describing or discussing the cost aspect of the WSN and the easing of development of the system. Moreover, there are many sensor nodes that can be used, which can be commercially sold in the markets with various prices as shown in Table 1.

Table 1. Some Commercially Sold Sensor Nodes in the Markets

Product Name	Vendor	Estimated Price per Node	Processor
Squidbee	Libelium	$200	ATmega328
Waspmote	Libelium	$220 (starter kit)	ATmega1281
MicaZ	Crossbow	$100	ATmega128L
TelosB	Crossbow	$100	TI MSP430
Mulle	Eistec	$200-$210	M16C/62P
WSN-32xx	National Instruments	$500	-
T-Node	SOWNet Tech.	$90	-

(Source https://www.iis.se)

Due to the high prices of the WSN nodes in the markets, agriculture experts and WSN developers are looking for a low cost platform and easy way to build up wireless sensor nodes for agriculture arena. Therefore, the aim of this paper is to develop a low cost wireless sensor network for a paddy field monitoring system based on the Arduino platfom. The Arduino is an open-source computer hardware/software platform for building digital devices and interactive objects that can sense and control the physical world around them. It provides easy to use hardware and software for developers, supports a rapid development platform for beginners, and is flexible enough for advanced users [8]. The proposed Wireless Sensor Network in this work is evaluated in the paddy field of Gowa regency that is one of rice producing areas in South Sulawesi, Indonesia.

In the remainder of this paper we describe the proposed system including outlines of the design criteria, which drive the platform design decisions and its estimated costs and present the experimental results in a paddy field test as well.

2. The Proposed Real-time Paddy Field Monitoring System

A. Requirements Specification

Paddy fields in Gowa regency, Indonesia almost have the same type and shape in every place in the area, so the design of WSN hardware and software should be used universally. A low-cost platform, low power and reliable in the hard environment where some areas might be far from energy infrastructures are important aspects that should be considered. The followings are requirements for sensor nodes, routers, and gateway nodes that should be met in this work.

- The communication band is 2.4GHz.
- The communication distance is about 80-120m.
- The data rate is 250kbps.
- The sensor platform accomplishes universal agricultural applications. The platform provides rich interfaces for the collection of digital and analog data.
- The platform is low cost and low power consumption. The platform is powered by 3.3V, 5V and 12V.
- The sensors are switched regularly and dynamically. The cycle length and frequency can be regulated to adjust the sensors' suspend mode.
- The gateway platform can receive a data from sensor nodes and send it to the Internet.

B. System Architecture

We now describe the proposed system architecture, functionality of individual components, and how they operate together to provide a real time paddy field monitoring system. The system consists of three layers: WSN layer, server layer, and presentation layer, which are connected to each other. The WSN layer is responsible for collecting paddy field conditions and transmitting them to the server layer; the server layer is responsible for storing the sensed data into a database, while the presentation layer is responsible for displaying information to agriculture stakeholders. In the WSN layer, sensor nodes sense the conditions of the paddy field such as temperature, air humidity, soil moisture, water level, and UV ligh intensity. They transmit the data to a gateway node via radio communication. If the locations of the sensor nodes are far from the gateway, we use router nodes to provide a multihop communication mechanism. In the gateway side, all received sensed data are then submitted immediately to the Internet cloud server via GPRS communication. Finally, agricultural stakeholders with their computers or mobile devices can access the sensed data in real time using their browser applications. Figure 2, shows the three layers and components of the proposed system and how they communicate with each other.

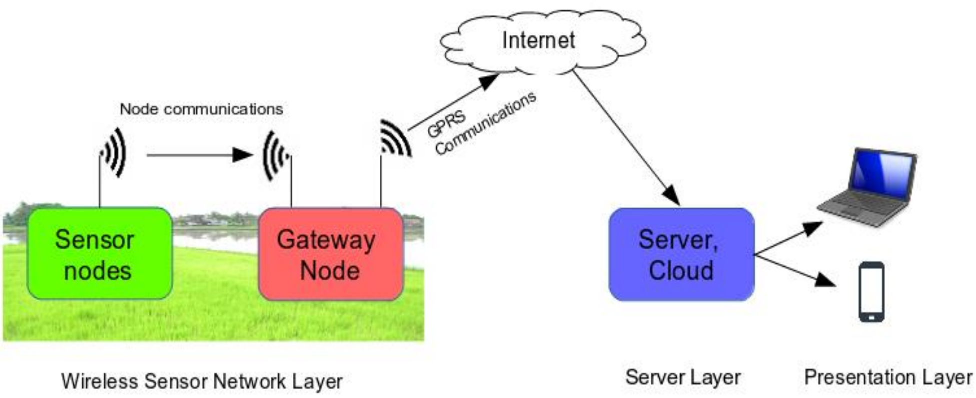


Figure 2. System Architecture for a Real Time Paddy Field Monitoring System

In this paper, the wireless sensor network layer consists of three types components:

1. Sensor Nodes (SN). The nodes perform sensing activities, processing the sensed data locally, and sending the data to a sink or gateway node (GW).

2. Router Nodes (RN). Same as the sensor nodes except they also can forward sensed data from other sensor nodes to a gateway. This node will be used if the sensor nodes cannot communicate directly with the gateway due to the limited communication range.
3. Gateway Node (GW). As a gateway, this node will receive all the sensed data from sensor nodes in the paddy field and send them to the Internet for further processing.

C. The Design of Sensor Nodes

To achieve our goal of providing a low cost and easy way to develop the WSN nodes for a paddy field monitoring system, Arduino has been selected as a main hardware platform both for sensor nodes and router nodes.

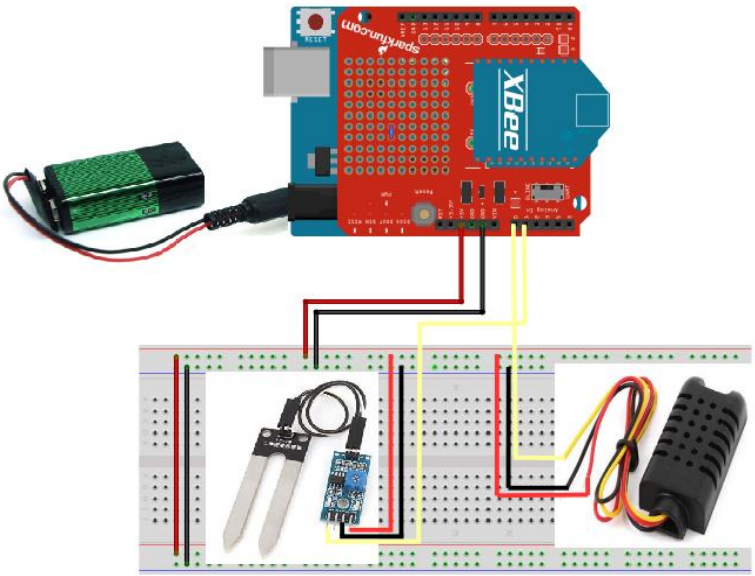


Figure 3. A Proposed Design for Sensor Nodes

The Arduino board provides a processing capability for the nodes. Two types of the Arduino board that are suitable for building low cost sensor nodes in this work are Arduino Uno and Pro Mini. Both the platforms have almost the same capability, but the Uno type offers a simple way to develop sensor nodes. For communication between sensor nodes, routers, and sink/gateway nodes, we use XBee series 2 modules to implement a ZigBee-Based communication system. The Xbee has been selected as the communication network tool because it is ideal for low-power, low-cost applications and is easy to use [13]. In the design, we equip our sensor node with three cheap sensor devices for agricultural applications such as: temperature, air humidity, and a soil moisture sensor. Figure 3 presents the design of the proposed sensor nodes. The schema shows XBee and its shield is installed on Arduino, an analog pin (0) of the Arduino is used to read the temperature and air humidity sensor, while an analog pin (1) is used to read soil humidity sensor data. A non-rechargeable 9 volt battery is installed to power the node. The following presents the technical specifications of low cost sensor node components that we use in this paper.

Speficifications of Arduino Uno Board (Arduino Web Site, 2016)

	• Microcontroller: Atmega 328P • Operating Voltage: 5v • Input Voltage (recommended): 7-12V • Digital I/O Pins: 14 (of which 6 provide PWM output) • Analog Input Pins: 6 • DC Current per I/O Pin: 20 mA • DC Current for 3.3v Pin: 50 mA • Flash Memory: 32 KB (ATmega328P) of which 0.5 KB used by bootloader • SRAM : 2 KB (ATmega328P) • EEPROM: 1 KB (ATmega328P) • Clock Speed: 16 MHz • Length: 68.6 mm and Width : 53.4 mm • Weight : 25 g

Speficifications of Xbee Series 2 (Digi Web Site, 2016)

	• Supply Voltage: 2.8 - 3.6 V • Transmit Current (typical) : 40 mA (@ 3.3 V) • Idle / Receive Current (typical): 40 mA (@ 3.3 V) • Power-down Current: 1 uA • Operating Frequency: ISM 2.4 GHz • Indoor/Urban Range : Up to 133 ft (40 m) • Outdoor RF line-of-sight Range : Up to 400 ft (120 m) • Transmit Power Output: 2 mW (+3dbm) • RF Data Rate : 250 Kbps • Dimensions : 0.960” x 1.087” (2.438cm x 2.761cm) • Supported Network Topologies: Point to point, Star, Mesh • Operating Temperature: -40 to 85o C

Specifications of DHT21 Sensor (Electrodragon web site, 2016)

<table>
<tr>
<td></td>
<td>DHT21 or AM2301
• 4-pin package
• Ultra-low power
• No additional components
• Excellent long-term stability
• All calibration, digital output
• Completely interchangeable
• Long distance signal transmission
• Relative humidity and temperature measurement
• Accuracy resolution: 0.1
• Measurement range: 0-100%RH
• Temperature measurement range: -40℃~ +80℃
• Humidity measurement precision: ±3%RH
• Temperature measurement precision: ±0.5℃</td>
</tr>
</table>

Specifications of Soil Sensor (Electrodragon web site, 2016)

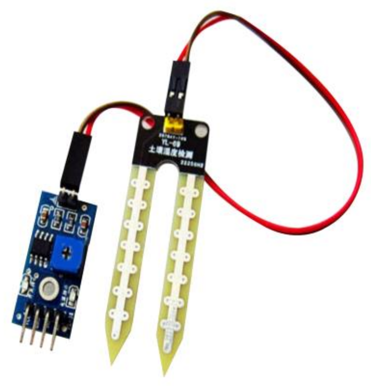
<table>
<tr>
<td></td>
<td>• When the soil moisture deficit module outputs a high level, and vice versa output low.
• Sensitivity adjustable the blue digital potentiometer adjustment
• Operating voltage 3.3V-5V
• Module dual output mode, digital output, analog output more accurate.
• With fixed bolt hole for easy installation
• Small board PCB size: 3cm * 1.6cm
• Power indicator (red) and digital switching output indicator (green)
• Comparator LM393 chip, very stable</td>
</tr>
</table>

Table 2, shows our selected components for one sensor node and its estimated cost.

Table 2. The Components of Proposed Sensor Node

Components	Estimated Price (USD)
Arduino Uno 3 (as the proposed main board)	$20
XBEE 2mW (S2)	$22
XBEE Shield (optional), this shield simplifies the task of interfacing an XBee with Arduino	$2.3
DHT21 sensor (Temperature & Humidity)	$3.8
Soil Sensor	$1.0

9V Battery Snap	$0.4
Case (for outdoor use)	$1.2

The hardware components that we used in this work make our proposed sensor nodes for agriculture cheaper than most of the WSN platforms on the market or than some studies have proposed, so far. Some studies use alternative platforms for the mainboard of the sensors node such as FS-ENGINE [9] and MCU MSP430 series [11-12]. The mainboard platforms in the previous studies are more expensive than the proposed ones. As the temporary gateway node for evaluation, we use an XBee module laptop with a modem GRPS connection as shown in Figure 4.

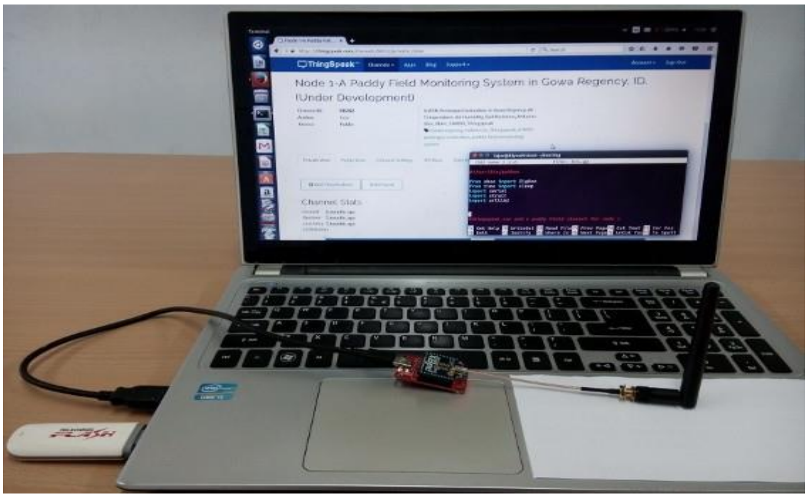


Figure 4. A Gateway or PC Basestation

First, the gateway reads the packet from the sensor nodes, then unpacks the packet to get sensing results and the identification number (ID) of the node, and stores them in text format, and finally puts the data into the IoT cloud server on the Internet. The application code of the gateway is implemented using the python scripting language. In the following are the steps of the gateway.

```
1. Initialize and open a serial port
2. Create an API object of XBee
3. Read the XBee packet
     Get the packet length
     If the packet length is compatible with the expected data length
         Unpack Node's ID, temperature, humidity, and soil data
         Put the temperature, humidity, and soil to thingspeak server
4. Repeat step 3 to next packet or step 5 to stop
5. End
```

D. Data Aggregation

Star architecture in this work connects each sensor node to sink/gateway directly. Sensed data will be sent from sensor nodes to the sink/gateway without router nodes.

When the nodes are started and a network is formed, sensor nodes sense the condition of the field (temperature, humidity, and soil moisture), store the data to the payload of the message, and send them to a gateway. The gateway receives the sensed data, extracts it, and puts the data onto the IOT Server on the Internet. Figure 5 shows the cycle of the activities on the sensor nodes.

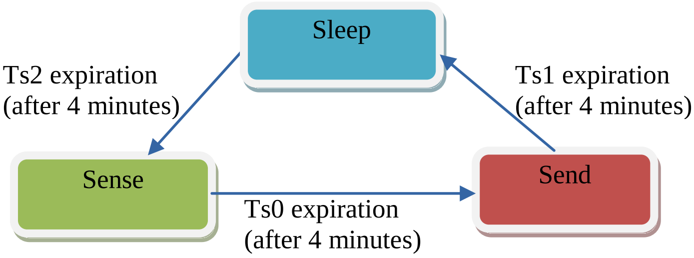


Figure 5. The Cycle of Activities of Sensor Nodes with T=4 Minutes

When the network is formed, every sensor node will have the following states sequentially:
1. **Sense**. In this state, a node is reading the sensed data, and stores them in the payload of the message.
2. **Send**. A node is sending the message including the sensed data to the gateway.
3. **Sleep**. A node is not doing any activities.

The cycle of the activities is four minutes. In the sensor nodes, the main activities are: **sense** and **send**. Conversely, on a gateway side the activities are: **receive** and **transmit** the sensed data to the Internet cloud server.

E. Internet of Things (IoT) Platform Services

To store and display the sensed data of the paddy field to the Internet cloud server, we use an open source IoT platform service such as thingspeak [13]. The platform service provides an application programming interface (API) to store and retrieve data from things (sensor nodes) using HTTP over the Internet or via a Local Area Network. Figure 6 presents the activities on the gateway side.

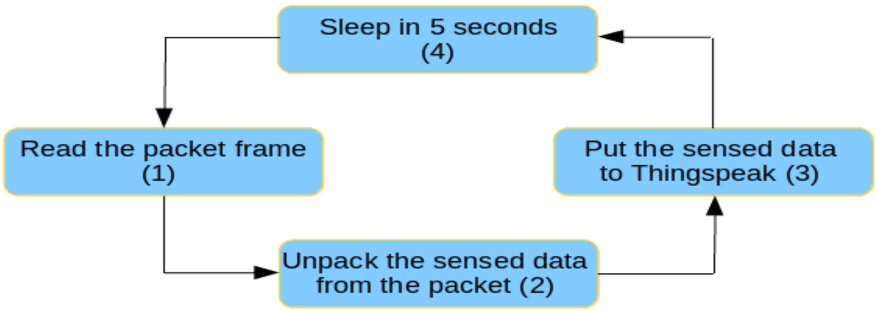


Figure 6. The Cycle of Activities of the Gateway

3. Evalution

To evaluate the proposed WSN, we conducted pre-evaluation and deployed two sensor nodes and a gateway in the paddy field of Gowa regency as shown in Figure 7. The evaluation shows that the sensor nodes are capable of sensing the conditions of the field such as temperature, air humidity, and soil humidity. In this experiment, we found the best of the communication range of the XBee modules from the sensor nodes to the gateway without packet loss is 80-90 meters. With the range, the sensor nodes send their sensed data to the gateway directly. On the gateway side, the received sensed data are transmitted immediately to the IOT thingspeak server successfully, and users are able to see the sensing results using internet browser applications. The IOT thingspeak service displays the data in graphs and updated them every time new data are received from the gateway. Figure 8, shows an example of sensing results of the paddy field displayed on the thingspeak service. The displayed data (temperature, humidity, and soil humidity) of sensor node 1 in the figure are valid. The soil humidity values are below 100. This means that the soil where the soil sensor is attached has much water.

Figure 7. The Prototype of Proposed Sensor Nodes in a Paddy Field Test (Left: Sensor Node 1, Right: Sensor Node 2)

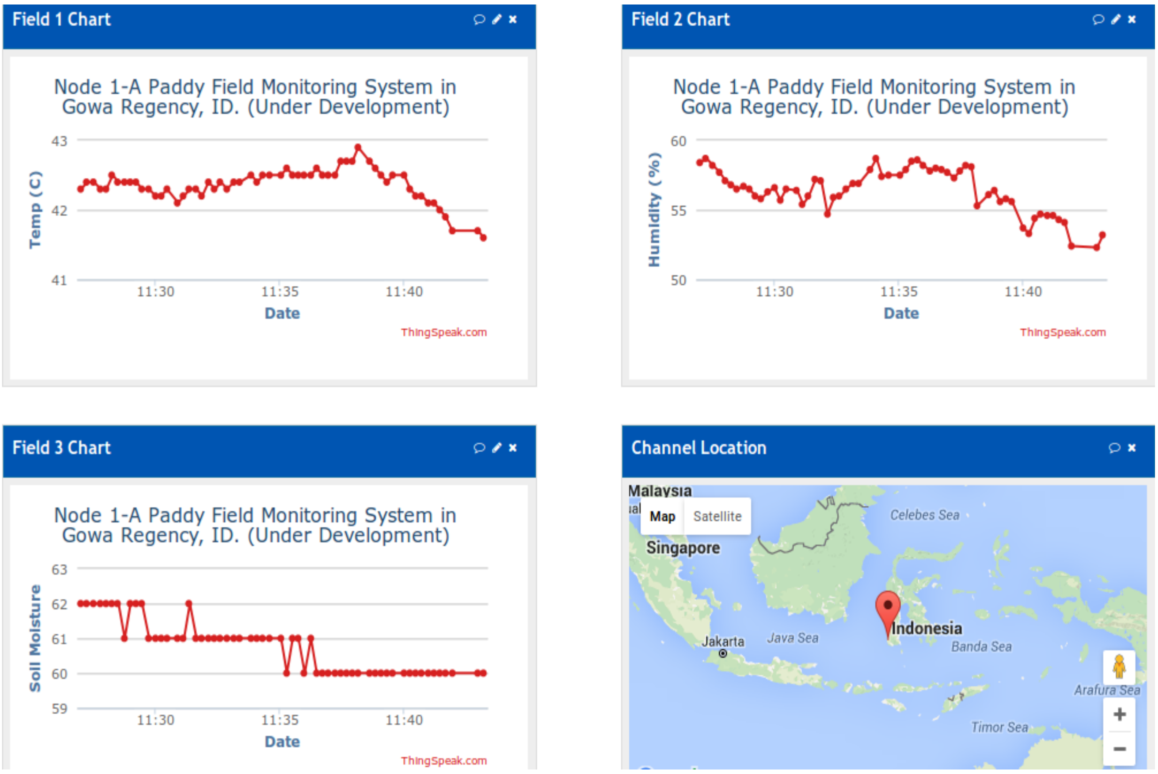


Figure 8. A Real-Time Paddy Field Sensing Results on a Thingspeak Service

4. Conclusion and Future Works

The wireless sensor networks (WSNs) for precision agriculture have important advantages, but the relatively high cost of the WSNs development may limit its use. In this paper, we have shown a low cost platform that reduces the cost significantly and increases its economic viability. The proposed WSN platform based on Arduino is easy to find on the market and easy to develop for real time paddy field monitoring systems. Evaluation results show that the proposed WSN is able to sense the paddy field conditions such as temperature, humidity, and soil humidity, and send the sensing results to the Internet cloud server for real-time display information.

In future work, we will design a special gateway for the paddy field monitoring system using a low cost platform and evaluate the proposed WSN for long term use.

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